TECHNISCHE UNIVERSITÄT
ILMENAU

50. Internationales Wissenschaftliches Kolloquium

September, 19-23, 2005

Maschinenbau von Makro bis Nano / Mechanical Engineering from Macro to Nano

Proceedings

Fakultät für Maschinenbau /
Faculty of Mechanical Engineering

Startseite / Index:
http://www.db-thueringen.de/servlets/DocumentServlet?id=15745

Impressum

Herausgeber:	Der Rektor der Technischen Universität Ilmenau Univ.-Prof. Dr. rer. nat. habil. Peter Scharff
Redaktion:	Referat Marketing und Studentische Angelegenheiten Andrea Schneider Fakultät für Maschinenbau Univ.-Prof. Dr.-Ing. habil. Peter Kurtz, Univ.-Prof. Dipl.-Ing. Dr. med. (habil.) Hartmut Witte, Univ.-Prof. Dr.-Ing. habil. Gerhard Linß, Dr.-Ing. Beate Schlütter, Dipl.-Biol. Danja Voges, Dipl.-Ing. Jörg Mämpel, Dipl.-Ing. Susanne Töpfer, Dipl.-Ing. Silke Stauche
Redaktionsschluss: (CD-Rom-Ausgabe)	31. August 2005
Technische Realisierung: (CD-Rom-Ausgabe)	Institut für Medientechnik an der TU Ilmenau Dipl.-Ing. Christian Weigel Dipl.-Ing. Helge Drumm Dipl.-Ing. Marco Albrecht
Technische Realisierung: (Online-Ausgabe)	Universitätsbibliothek Ilmenau ilmedia Postfach 10 05 65 98684 Ilmenau
Verlag:	isle Verlag ISLE, Betriebsstätte des ISLE e.V. Werner-von-Siemens-Str. 16 98693 Ilmenau

ISBN (Druckausgabe):	3-932633-98-9	(978-3-932633-98-0)
ISBN (CD-Rom-Ausgabe):	3-932633-99-7	(978-3-932633-99-7)

Startseite / Index:
http://www.db-thueringen.de/servlets/DocumentServlet?id=15745

50. Internationales Wissenschaftliches Kolloquium
Technische Universität Ilmenau
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P. Kuosmanen / J. Juhanko

Predictive 3D Roll Grinding Method for Reducing Paper Quality Variations in Coating Machines

ABSTRACT

The predominant trend in paper machines is towards higher running speeds, better runnability and higher and more even quality of paper. In blade coating the thickness of the coating film on the paper surface is found to be dependent on the run-out of the backing roll, which supports the paper web against the metering blade. These coexistent requirements create new demands on the manufacturing of the rolls for production conditions.

A new predictive 3D grinding method has been developed. It consists of a measuring system which can verify the rotational and geometrical errors of the roll at running speed and a 3D grinding system which controls the grinding process according to the information thus gained. In this study, the experiments were carried out with the backing rolls of a coating station on a medium-weight coated (MWC) paper production line.

The predictive 3D grinding reduced the machine direction (MD) ash variation by 65% and gloss variation by 87%. The thickness variation from the backing rolls was reduced by 69%. Reduced gloss variation improves the print quality of LWC paper and more even paper thickness reduces excitations and therefore improves runnability in calendering, winding, and printing. The run-out tolerance of 50 µm for backing rolls at running speed should be reduced and that can not be achieved by tightening the traditional roll manufacturing tolerances.

INTRODUCTION

In increasing the production capacity of paper machines, the predominant trend is towards higher running speeds rather than wider machines. It is envisaged that the trend will also continue in the future. As a result of higher running speeds, the rotational speeds of rolls and vibration problems have increased. The latest paper machines on the market are designed for a running speed of 2000 m/min. The paper-making process itself does not seem to be a limiting factor in increasing running speeds. For example, a pilot coating machine has a speed record of over 3100 m/min [1] and pilot paper machines have been running at over 2500 m/min. The speed difference between pilot and production machines is a result of the difficulties of making a wide machine instead of a narrow one. A wide machine has longer rolls, which means reduced natural frequency. In rolls with a steel body, the only effective way to increase the natural frequency is to increase the bending stiffness by increasing the diameter of the roll. Consequently, if the diameter is increased without the thickness of the cylindrical shell also being increased, the stiffness of the shell is reduced.

There are only a few studies concerning the correlation between roll geometry and variations in paper quality. Normally, the roll is considered to be an ideally round component in all circumstances. An exception was a study by Parker that mentioned roll roundness error as one source of excitation for calender barring problems [2]. This study was of the barring of newsprint by four-roll calender stacks. Parker also developed a theory that corrugation of certain wavelengths would grow spontaneously as a result of certain irregularities left after grinding. In addition, a curvature gauge was constructed, which proved that bar-marked rolls were corrugated. Later on, roll corrugation is mentioned as a source of excitation [3,4].

The first study of non-circular machining technology applied to compensating for the effects of structural errors in a roll was published in the early ’90s [5]. The aim of the study was to optimise the contact pressure in the nip of two cylinders, one of which had varying flexural stiffness. Non-circular turning of the roll reduced nip-pressure changes to one third, compared with the conventional machined roll. Another important step was the development of a four-point roundness measurement method and apparatus [6]. By means of this technology, it became possible for the first time to take effective roundness measurements of paper machine rolls. Later, this technology was applied to a device, which measures the dynamic behaviour of the high-speed rotating rolls [7, 8].

The main objective of coating is to increase the smoothness of paper considerably. Besides this, coating increases gloss, surface strength, and opacity. Coating also decreases ink absorption [9]. In printing, the smoothness of the gloss is important. This research is focused on improving coating film evenness in the coating process by reducing the errors deriving from backing rolls. Thus, in this research paper, ‘quality’ refers to the quality of coated paper. The main quality properties to be measured in coated paper are ash, basis weight (also called grammage), thickness, and gloss. Ash variation has a good correlation to coating variation, because, compared with the coating material, the base paper has a low ash content.

The higher running speeds of coating machines have highlighted the importance of the dynamic behaviour of rolls and the runnability of the paper machine in general. At the same time, the paper produced must have a higher and more even quality. One of the most sensitive unit processes in paper production is paper coating. In blade coating, the thickness of the coating film on the paper surface is heavily dependent on the run-out of the backing rolls, which support the paper web during the process. The run-out tolerance of the backing rolls at running speed has recently been around 50 µm and, and in many cases, the run-out should be reduced to 30 µm or even lower. The new demands can no longer be met by tightening the roll manufacturing tolerances, which has traditionally been the solution to the problem. The accuracy of traditional manufacturing technology can no longer be increased at reasonable cost. The run-out in running speed is not affected only by manufacturing tolerances; there are also problems with bearing accuracy and material homogeneity. Variations in material stiffness and heat expansion cause geometrical and rotational errors in the roll.

Machine direction (MD) variations have also been misinterpreted as cross-direction (CD) variation. Fu and Nuyan [10] proved that the aliasing effect of MD variability is present in CD profiles measured by scanning sensors. Originally, the aliasing problem is not truly a CD problem, but the CD controller acting on these false wavelengths introduces actual CD problems.

Problems with new high-speed machines are similar to those with the old machines, whose speed needs to be increased over the original design speed. The roll behaviour under production conditions is no longer satisfactory and major investment is needed to replace the old rolls with new and more accurate ones.

Could it be possible to increase the running speed of a paper machine and, at the same time, reduce variations in paper quality by using a non-conventional grinding method? This new predictive 3D grinding method should measure roll behaviour in a production environment and consider using it in roll grinding. The geometry after non-circular grinding would be far from cylindrical but, in the production environment, the roll would achieve ideal geometry and therefore would work better than conventionally machined rolls.

METHODS AND MATERIALS

The development of roll measurement and machining technology can be divided into three generations. The first-generation technology can measure and compensate for diameter variation of the roll in the axial direction. Typically, the error comes from the slideway straightness error of the machine tool. The second-generation technology introduces roundness measurement and error compensation. With this technology, rolls can be machined very accurately to a desired, usually cylindrical, geometry. All the required measurements are taken in the roll grinding shop. The same kind of technology has been published in other fields, too. Advanced control technology for compensating spindle rotational errors [11] and for single-point diamond turning [12] have been presented. There are also novel applications in the manufacturing of optical components [13]. The technology can also be applied in machining pistons for combustion engines [14, 15].

The third-generation roll machining technology optimises the roll geometry to the production environment. The rolls may be machined to oval and curved shapes or some other desired geometry. In the production environment these rolls achieve an ideal geometry and manage the process task better than rolls machined in the traditional way. The run-out behaviour at running speed is not affected by machining accuracy only but also by the rotational accuracy of the bearing assembly and the homogeneity of the roll material.

Fig. 1. Predictive 3D grinding system: Dynamic behaviour measurement (left) reveals dynamic deformation of the roll. Grinding system (right) provides the desired geometry to within an accuracy of 1 µm [17].

The experimental device, shown in Figure 1, consists of a measuring system, which can verify the rotational and geometrical errors of the roll at running speed, and a 3D grinding system, which controls the grinding process according to the measured information to within an accuracy of 1 µm. The new non-circular grinding method was applied to two similar backing rolls of a coating station. In this study, the results achieved with one roll are presented. The experiments were carried out on a medium-weight coated (MWC) paper production line at a paper mill.

RESULTS AND DISCUSSION

The roll *roundness error* at production speed in the middle cross-section was reduced from 55 to 13 µm (i.e. by 76%). At the ends, the roundness was already very good after traditional machining and the roll roundness improved by only 38% on average, from 20 to 12 and 14 to 9 µm.

The test roll exhibited remarkable asymmetric deformation as a function of running speed, as illustrated in Figure 2. This can be explained by the roll manufacturing process, in which the roll is welded together from two pieces of different lengths. Both parts have different mass distribution and stiffness, which leads to asymmetric deformation under high centrifugal forces. At the ends the stiffness of the end plates minimises the deformation. The residual error derives from the rotational error from the bearings, which is copied to roundness error during the grinding process.

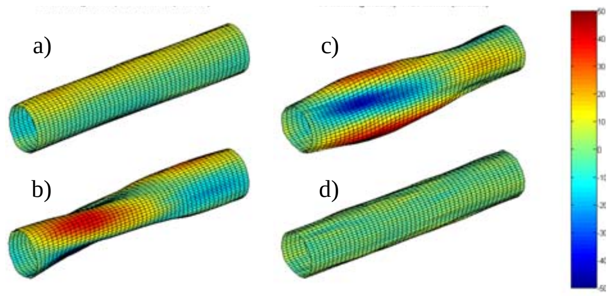

Fig. 2. Geometry of the test roll with traditional grinding at a low speed of 50 m/min (a) and at a production speed of 1120 m/min (b), and after predictive 3D grinding at low speed (c) and at production speed (d) respectively.

With the 3D grinding technology the roundness of the rolls at running speed (Figure 2d) was significantly better compared to traditional grinding (Figure 2b). The result shown in Figure 2b is inverted and used as control for the 3D grinding system to obtain the static geometry shown in Figure 2c. The dynamic result in Figure 2d was even slightly better than the geometry at low speed after traditional grinding (Figure 2a).

The *run-out* is a sum of the out-of-roundness and rotational error motion of the roll axis. In flexible rotors eccentricity (1. H) is normally the main component of run-out, as shown in Figure 3. Backing rolls with a large diameter and thin cylinder wall are an exception because of shell deformation as a function of running speed.

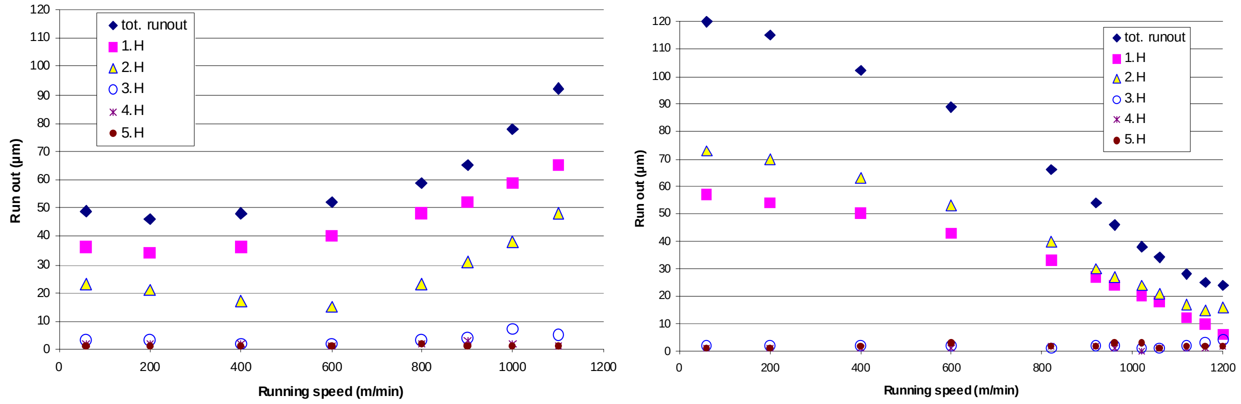

Fig. 3. Run-out with traditional grinding technology (left) and with predictive 3D grinding as a function of running speed. Total run-out and five harmonic components are shown.

The test roll had a significant second harmonic, which derives from the oval-shaped deformed geometry at running speed. Predictive 3D grinding improved the roll run-out by 70%, from 92 µm to 28 µm, at production speed in the middle cross-section, as shown in Figure 3. At the ends, the run-out improved by 43%, from 37 µm to 14 µm and 33 µm to 25 µm respectively.

The paper analysis shows a clear reduction in *ash variation* after predictive 3D grinding. A time domain analysis of a 100 m long sample shows that the peak-to-peak value has diminished from 3.9 g/m^2 to 1.5 g/m^2 (Figure 4). The paper grade was not exactly the same in both samples. The paper had more coating in the latter test (13.5 g/m^2 vs. 13 g/m^2 per side), where the backing rolls were ground with predictive 3D grinding. Normally, a greater thickness increases the thickness variation. Hence, the experiments would have most probably shown an even greater improvement with the same paper grade.

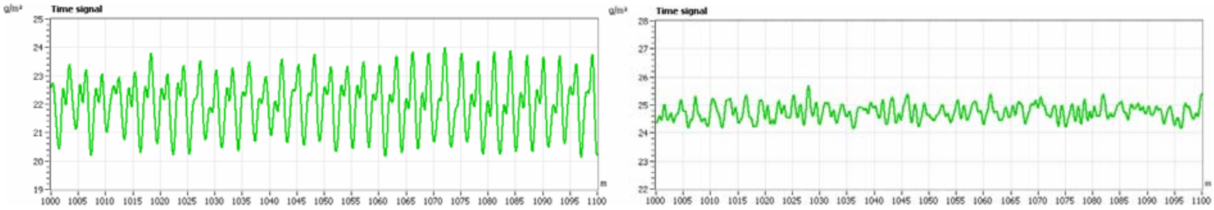

Fig. 4. Ash variation of the coated paper in the time domain in MD before (left) and after predictive 3D machining.

The paper analysis shows only a small reduction in thickness variation after predictive 3D grinding. A time-domain analysis of a 100 m long sample shows that the peak-to-peak value has changed from 2.4 µm to 2.1 µm (Figure 5).

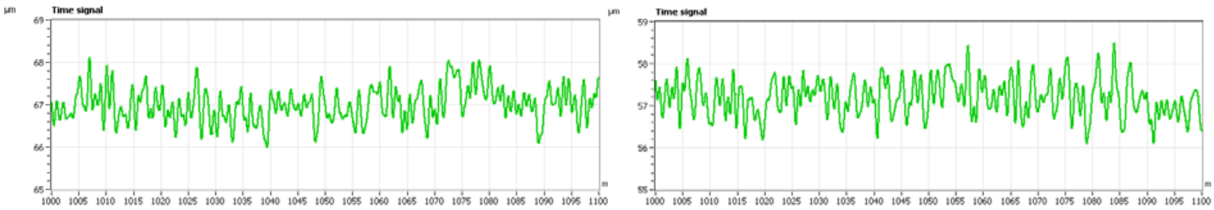

Fig. 5. Thickness variation of the coated paper in MD before (left) and after predictive 3D machining.

The paper analysis shows a clear reduction in gloss variation caused by the backing roll of the coating station after predictive 3D grinding, as shown in Figure 6. A time-domain analysis of a 100 m long sample shows that the peak-to-peak value has diminished from 7.9% to 2.9%.

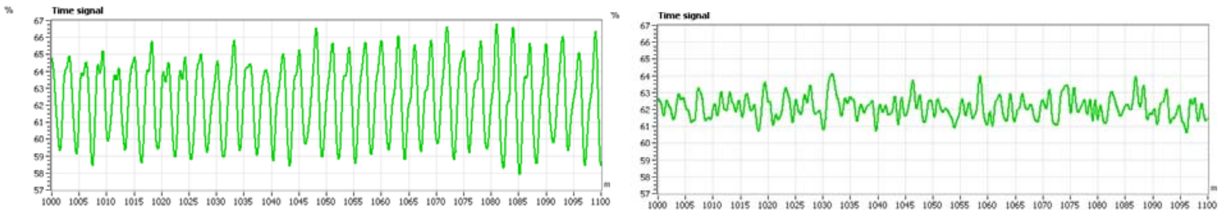

Fig. 6. Gloss variation of the coated paper in MD caused by the backing roll before (left) and after predictive 3D machining.

Table 1 presents variations in paper characteristics, synchronised to the rotating frequency and the harmonics of the backing roll. The results are presented after traditional grinding and after predictive 3D grinding. The values are based on spectral analysis of the total length of 4000 m long samples.

	Traditional grinding	3D grinding	Reduction
Ash (g/m^2)	2.0	0.7	65
Thickness (µm)	1.3	0.4	69
Gloss 1 (%)	5.3	0.7	87

Table 1. The influence of predictive 3D grinding of the backing roll on paper quality variation. The numbers are peak-to-peak values. Low pass filtering is 358 Hz.

CONCLUSION

With predictive 3D grinding technology the roundness of the rolls was better at the running speed than with traditional grinding. Additionally, the run-out of the test rolls was reduced at the running speed. As a result, the process runnability was better, and grammage and gloss variations were reduced as well.

The benefit of the results in paper coating is that no extra energy is needed to dry an uneven layer of wet coating material. If the process is limited by drying capacity, the more even coating layer enables a small speed increase. Paper with less coating material will no longer be over-dried, which improves its strength properties. The main advantage, however, is the effect on printing quality.

The technology developed is cost-effective and can easily be applied to old machines on a paper production line where there is pressure to increase running speeds and paper quality. It has been proved that with this technology old rolls will run even better than the new rolls that are available. In new high-speed paper machines this technology provides a new tool to meet the tightening tolerances of rotational and geometric accuracy.

The method can also be applied to different kinds of rolls to compensate for systematic errors such as uneven thermal expansion and uneven bending stiffness, which cause, for example, nip force variations.

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Authors:

Professor Petri Kuosmanen
Research Manager Jari Juhanko
Helsinki University of Technology, Laboratory of Machine Design, P.O.Box 4100
02015 TKK, Finland
Phone: +358 9 451 3544
Fax: +358 9 451 3549
E-mail: petri.kuosmanen@tkk.fi